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Integrating Fire and Explosion Risk Analysis, Fire zones, Fire and Gas Detection, Emergency Shutdown and Blow-down, and Fire Fighting capabilities in Natural Gas Liquid (NGL) Plant

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Abstract

Managing process safety risk in Natural Gas Liquid (NGL) plant is always a challenging task, especially when it comes to integrating the output of fire and explosion risk analysis into the detail design tasks. Some of which are

- optimizing plant layout,
- defining fire zones, emergency shutdown and blowdown scenarios for flare capacity,
- laying out fire and gas detectors, action on confirm gas or fire detections,
- locating emergency and blowdown valves,
- arranging active fire protection on overall plot plan and processing units,
- passive fire proofing on steel structures and vessels supports,
- 3D model review of safety systems.

This paper will provide systematic approach of integrating process safety deliverables during detail design stages of the project and thereby demonstrating ALARP for the key design decision made during the project phase to deliver an inherently safer facility.

Introduction

The first and foremost thing in integrating process safety and risk studies is to define a robust project loss prevention philosophy clearly touching the subjects on how process safety will interact with other engineering disciplines, provide guidance that how risk and safety studies will be performed and integrated continuously when engineering work is begin performed. Process safety or technical safety team shall be fully aware of its important role on the project and coordinate with other engineering disciplines to provide proactive support and inputs to design development. This paper is concentrating on active involvement of process safety team on Natural Gas Liquid (NGL) Project during detail engineering phase. Since, gas processing plants are different than refinery process, where toxic and flammable risk imposes different pictures in terms of risk management. Such as, implying risk based approach in active and passive fire protection, process plant layout, understanding jet fire from high pressure gas release, pool fires from low pressure releases of cryogenic liquids and delayed ignition of gas cloud resulting into explosion overpressure in a congested areas of gas processing plant.

Integrating Risk and Safety Deliverables

During initial phase of the details engineering, loss prevention philosophy and plan shall define process safety guidelines and how process safety engineering work will be performed, including deliverables schedule, involvement of process safety team in several studies in risk identification and management. These primary and the most important documents shall be defined in much details so that it provides path forward for the entire phase of the project. Any changes in project loss prevention philosophy and plan shall be managed through proper channel or Management of Change Process.

Developing process safety and risk deliverables schedules shall align with other engineering discipline deliverables (in terms of input or output). Process safety and risk schedule shall drive through entire project deliverables and activities to be performed either by process safety team or consultant. Outputs from risk and safety studies shall provide inputs to other engineering deliverables, design development and workshops such as Layout review, Hazard and Operability (HAZOP), Safety Integrity Level (SIL)/Layer of Protection Analysis (LOPA) etc.

Plot Plan Review

Plot plan and site layout review initially involving multi-disciplinary engineers and inputs provided for the development of layout based on knowledge of fire and explosion risk, international guidelines for spacing processing units are valuable to optimize plant layout for further engineering work.

Hazard Identification (HAZID)

Hazard identification involving multi-disciplinary engineering team in a brain storming session provides comprehensive list of hazard identified from non-process and process areas of the NGL Plant. Further, identification of Major Accident Hazards (MAHs) becomes back-bone of developing Design Safety Case or Control of Major Accident Hazards (COMAH) or Health, Safety, Environmental Impact Assessment (HSEIA) Report depending on corporate and regulatory requirements. Hazard identification provides scenarios to be considered in fire and explosion analysis and Quantitative Risk Assessment (QRA).

Fire and Explosion Analysis

Fire and explosion analysis is normally performed by consultant using software to simulate impact for fire scenarios in each fire zone. In NGL plant predominant fire scenarios may be jet fire and flash fires, there is the potential for pool fires with low pressure releases of cryogenic liquids. Delayed ignition of gas cloud within congested process areas of the fire zone may generate significant explosion overpressure.

The analysis shall provide information regarding worst case fire and explosion scenarios and impact zones/distances, risk contours for different radiations, overpressure risk contours for different pressure. Results of fire and explosion analysis shall be useful for defining fire zones on plot plan, relocating fire potential equipment, optimizing plant layout and distances between equipment, requirement for active and passive fire protection, minimizing escalation potential between equipment within the unit and escalation to other processing units.

Flare radiation and flame out dispersion analysis is very important for location of flare in NGL Plant and is many times performed as part of fire and explosion analysis. Flare radiation for the worst case blowdown scenarios from the processing unit such as liquefaction unit of the NGL Plant is the governing case of flare design. Sterile zone around flare is defined based on these radiation analysis and API guidance. Location of tall structures, platforms shall have minimum impact from flare radiation where operating staff and equipment are exposed. Flame out condition of flare is another scenario for the worse case blowdown event to see if any heavy gases flammable concentration does not reach ground level or any elevated structures, platform and ignition sources. Fire and explosion analysis provides key input for defining fire zone on plot plan and firewater system design.

Fire Zones

Fire zones layouts for the facility are prepared for each process units based on separation distances between processing units using results of fire scenarios from fire and explosion analysis. These layouts are used for further detailed engineering work such firewater layouts drawings, firewater demand calculation and developing emergency shutdown and blowdown philosophy for fire scenarios in each fire zone.

Firewater System Layouts

Firewater System Layouts for entire facility including non-process and process areas are developed to fire fight different fire scenarios in each fire zone based on range of jet fires and pool fires identified from fire and explosion analysis, and NFPA requirements. Most fire scenarios in NGL Plant are gas fire with few pool fire scenarios from low pressure releases of cryogenic liquids, heavies and diesels fuel storage. Thus, the primary objective for firewater system is to prevent escalation between processing equipment within the unit and further escalation to other processing units. Deploying automated fire fighting system such as deluge spray system on process vessels and equipment is important where manual fire fighting is not possible. Above ground fire fighting equipment such as hydrant, monitors (with foam application where needed) and deluge spray system are best located based on fire scenarios and firewater coverage required.

Firewater Demand

Firewater demand is calculated based on firewater system layout showing above ground fire fighting equipment in each fire zone for effective fire fighting. Firewater demand is calculated for hydrocarbon pumps, tanks, vessel and equipment surface areas requiring fire water coverage in each fire zone based on NFPA requirements. The highest demand of firewater in any fire zone becomes the basis for designing firewater systems such as sizing firewater pumps, sizing firewater main and above ground fire fighting equipment.

Fire Proofing

Fire proofing schedule is developed based on fire potential equipment in compliance to API 2218 and international standards. Fire proofing layouts are then later developed to provide extent of fire proofing requirements for steel structures and supports for vessels and equipment. Any additional requirement of fire proofing shall be looked at from fire and explosion analysis based on risk contours for 37.5 kW/m2 radiation at frequency of 10-4/yr. Thus applying risk based approach for fireproofing requirement is a key aspect for minimizing escalation potential in NGL Plant.

Hazardous Area Classification

Hazardous area classification schedule and layouts are the primary requirement for classification of electrical equipment within the process units and fire zones for better ignition control. Thus, hazardous area classifications are key specification for the design requirement of electrical equipment, cables, terminal/junction box, pump motors etc.

Fire and Gas Detection

Fire and gas detection layout in NGL Plant is developed preliminary based on fire and gas detection philosophy. The hydrocarbon and toxic (if required) gas detectors layout shall cover each equipment, pumps, vessels and leak sources within each fire zones. Gas detectors layouts shall cover entire fire zone with point type and open path detectors in combination for appropriate voting logic for executive action. Similarly, fire / flame detectors shall be provided with fire zone covering equipment, vessels, pumps for confirmed fire detection and executive action required for emergency shutdown and blowdown.

3D Mapping of fire and gas detectors for effective coverage is very important in any fire zone of NGL Plant, especially to optimize fire and gas detectors 2D layouts initially developed. Based on experience for onshore NGL Projects, target confirmed fire and gas detection coverage of 90% for alarm (1ooN detection); and 85% for control/executive action (2ooN detection) are commonly used. Emergency shutdown and blowdown for each fire zone and overall NGL Plant is to minimize fire and explosion risk and to prevent escalation. Confirmed gas detection to isolate/shutdown process units and/or overall NGL Plant, and confirmed fire detection to staggered blowdown/depressurized process units and overall NGL Plant within flare capacity are considered, with few exceptions of some essential units for emergency services in place. Blowdown scenarios from liquefaction unit and upstream gas processing units of NGL Plant are further studied in detail to define governing cases for the design of flare capacity and also to build logic for staggered blowdown from NGL Plant.

Quantitative Risk Assessment (QRA)

There are several expectations by the project team form Quantitative Risk Assessment (QRA) for the NGL Plant. This study normally performed by risk and safety consultant provides inputs to important mitigation measures for the safety of operating staff and surrounding public populations. Governing scenarios contributing to individual and societal risk are discussed thoroughly in this report, mitigation measures are identified and further ALARP demonstration performed. Thus, QRA help to improve decision-making process by highlighting the scenarios that contribute most to overall risk on NGL Project. Focusing on these helps to meet project risk tolerability criteria and demonstrate that risks are as low as reasonably practicable (ALARP).

ALARP Demonstration

ALARP demonstration is a continual exercise which process safety team need to perform. ALARP demonstration can be based on standards, guidelines, qualitative or quantitative methods to justify that through assessment is performed for making any decision or changes during detail engineering phase of the NGL Project. Documenting ALARP demonstration and decision made is the key aspect of Process Safety Management (PSM).

RAM Analysis Reliability Availability and Maintainability (RAM) analysis provides production availability of NGL plant to meet desired production capacity considering availability of process equipment. There are not much of process safety inputs to the RAM Analysis. However, it provides insight of criticality of system and equipment from production point of view. RAM analysis for NGL plant covers interfaces, such as availability of upstream gas supply and downstream Cracker Plant.

Occupational Health Risk Assessment (OHRA)

Occupational Health Risk Assessment (OHRA) is a qualitative brain storming exercise to identify health risk during construction and normal operation phase of NGL project. OHRA reports provides list of actions to minimize health impact on construction and operating personnel. Appropriate measures are taken prior to performing hazardous activities. Requirement of medical facilities such as clinic, ambulance, trained doctors and nurse, medicine, medical evacuation means are the key requirements for NGL Plant located in a remote area. Health risk assessment is one of the elements of HSEIA report normally submitted to governing authority of the region for an approval of the project.

Bow Ties Analysis

Bow ties development for identified Major Accident Hazard (MAHs) during HAZID are further studies in a qualitative brain storming session with multi-disciplinary engineering team to identify preventive and mitigating barriers of the top event. Engineering team provides inputs to bow ties development with barriers in place as part of engineering for NGL Plant. Barriers are normally physical barriers or an activity called as safety critical activities. In NGL Plant most of the top events are loss of containment – hydrocarbon releases. Bow ties analysis provides list of safety critical elements and activities which need to be in place and further specification are prepared for its performance to prevent and mitigate consequences.

Safety Critical Elements (SCEs) and Performance Standards

Design performance standards are developed for each Safety Critical Elements (SCEs) identified from bow ties analysis. Performance standards include functionality, reliability/availability, survivability and dependability of safety critical element. These Performance standards shall align with specification developed for each SCEs. Process safety and risk studies such as fire and explosion analysis provide inputs to development of performance standards reliability/availability and survivability criteria. Assurance methods are also defined in performance standard for further assurance during Factory Acceptance Test (FAT) and Site Acceptance Test (SAT) etc.

Escape, Evacuation and Rescue Analysis (EERA)

Escape, Evacuation and Rescue Analysis (EERA) for onshore NGL facility is much simpler than for offshore facilities. EERA qualitatively examine and evaluate the effectiveness of EER facilities on onshore NGL Plant from major accident events which could occur during normal operations. This study identifies scenarios from fire and explosion analysis that would necessitate the use of the EER facilities. EERA shall determine the availability of escape routes from major accident event, and the potential impairment of EER facilities, when they are required. One of the main objectives of EERA is to check that defined EER goals and objectives are met, and if not, actions are generated to meet the goals.

Health, Safety and Environmental Impact Assessment (HSEIA)

The health, safety and environmental impact assessment (HSEIA) is a systematic approach for identifying the impact of new NGL Plant to health, safety and the environment. HSEIA report demonstrate compliance with HSE legislation; showing that all HSE hazards, including major accident hazards, occupational health hazards and environmental impact have been identified, assessed and mitigated. HSEIA report overall include the environmental impact assessment (EIA), a control of major accident hazards (COMAH) and an occupational health risk assessment (OHRA). Health, safety and environmental studies and assessment performed during the project are detailed in HSEIA Report to demonstrate that:

- HSE Management System is in place for prevention of major accidents hazards
- Health and safety hazards and environmental impacts have been identified, recorded and assessed
- Environmental impacts and risks are managed
- Safety critical equipment and systems are in place
- Emergency plans have been prepared
- The risks of project activities are ALARP (as low as reasonably practicable)

HAZOP and SIL/ LOPA

Prior to HAZOP and SIL/ LOPA design review meeting is conducted to review Process Flow Diagrams, Utility Flow Diagrams (UFDs), Process Description, Process and Instrumentation Diagrams (P&IDs), safeguarding / IPF narrative, Process Data Sheets, Site and Plant Layouts, Active and Passive Fire Protection Layouts, design documents and calculations. Process safety team active involvement in design review workshop provide valuable inputs to design development and further in preparation/achievement for other milestone activities.

Hazard and Operability Study (HAZOP) and Safety Integrity Level (SIL)/Layer of Protection Analysis (LOPA) are important milestone in detailed engineering for NGL Project. HAZOP can be conducted separately or in integration with SIL/LOPA for any project. These qualitative analysis followed by semi-quantitative exercise provides systematic identification of process hazards for different modes of operations which may go wrong due to failure of control system, human error or design errors. Identifying independent layer of protection (safeguards) and procedures to prevent failure resulting into serious consequences and further to assign reliability/availability targets for safety functions is important step in process safety management, inherent safety in design and operation of NGL Plant. Process safety team active participation in these important exercises are critical, since process safety and risk studies conducted prior to HAZOP, SIL/LOPA have significant inputs process hazard identification, defining consequences correctly and qualitatively assigning risk ranking as per project risk matrix with reference to Fire and Explosion Analysis, Quantitative Risk Assessment (QRA), and other related risk studies.

Project HSE Review (PHSER)

Project HSE Review (PHSER) is an audit to assure that HSE activities and deliverables are performed systematically during detailed engineering phase of the project. PHSER identifies gaps with reference to project specification and standards in process safety deliverables/activities performed on the project and provide list of actions or mitigation measures to rectify or resolve within definite time period. During detail engineering phase of NGL Project, it is advisable to conduct PHSER at 30%, 60% and 90% Model review. Subsequent PHSER are conducted at Construction Stage, Pre-Start-up Stage and Operation Stage (~12 months after commissioning) of the project.

Noise Analysis

Noise analysis is an environmental deliverable and is performed on a project to show expected noise levels during normal operation and emergency conditions. During detailed engineering phase of NGL Project, noise mapping is performed considering vendors information of noise level from rotating equipment (which generates high noise) provides noise contours mapping indicating high noise areas and impact within plant premises and beyond site boundaries causing disturbance to nearby population and habitat. Noise mitigation measures are provided to prevent health impact to operators working in plant premises and surrounding population.

Human Factor Engineering (HFE)

Human Factor Engineering (HFE) during detailed engineering phase of the NGL project is to ensure the implementation of HFE principles in to the design as per project specification and international standards. HFE review during details engineering include the following.

- Assure layout of packaged equipment has the appropriate level of HFE review
- Provide structures work process to determine access and size requirement for elevated work areas
- Provide structures work process to determine valve selection
- Ensure that all controls and display/instruments and other operated machineries can be reached, operated and viewed effectively and safely by operators
- Ensure that the need for safe and efficient maintenance tasks has been incorporated into design

- Ensure that all areas of the plant and equipment can be assessed and evacuated safely and efficiently under normal, adverse and emergency conditions
- Ensure that requirements for lifting, pulling and pushing of equipment, both manually and mechanically, have been considered bearing in mind the capabilities of expected user population
- Ensure environmental requirements applicable to human health, safety and performance including noise, lighting, vibration, climatic conditions and proximity to hold, cold, hazardous and contaminated equipment or areas have been addressed
- Ensure the ease and safety of construction operations

HSE Action Tracking and Closeout

HSE action tracking and closeout includes all risk and safety studies actions closeout with proper justification/evidence to ensure that actions generated are systematically reviewed, implemented and closed on the project. This continual exercise performed by process safety team provides assurance to the project management and is important step in Process Safety Management (PSM). Actions generated from HAZID, Fire and Explosion Analysis, QRA, HAZOP and SIL/LOPA, EIA, Bow ties, COMAH, HSEIA and other studies are included in this action tracking and closeout.

Pre Start up Safety Review (PSSR)

The most important and final requirement for managing process safety during detail engineering phase of NGL Plant is Pre Start-up Safety Review (PSSR). PSSR confirms that all health, safety, security, environmental and human factor requirements have been addressed satisfactorily and the facility is "ready to start-up".

Objectives of Pre Start up Safety Review (PSSR) are to ensure that

- Facilities and equipment are built and installed in accordance with design standards
- All operating procedures are developed and related process operator training are adequate and completed prior to the introduction of hazardous materials into the process
- Safety reviews are conducted
- All recommendations from HSE studies are implemented prior to start-up

Pre Start-up Safety Review (PSSR) requires identifying, documenting and managing all start-ups from all type of shutdown during a process ensuring that all the HSE requirements have been analysed and the system is ready to start ensuring a safe environment.

Conclusion

Overall integration of all process safety studies and deliverables provide significant success to resolve complex issues arising during detailed engineering phase of NGL Project. Process safety and risk studies are so much related with engineering work performed by other engineering discipline, that awareness to remain proactive, participate and provide inputs when needed is essential for overall safety in design. Through knowledge and vigilance to keep track of inputs and outputs of each deliverables by process safety team in coordination with project team provides inherently safer NGL Plant.